Neutron shielding requirements for MW/m D-^{3}He-burning rocket engines

Kevin P Griffin[†], Matthew T Walsh[†], R. Feder[*], and S.A. Cohen[*]

[†]Mechanical & Aerospace Engineering Dept., Princeton University, Princeton, NJ 08540
[*]Princeton Plasma Physics Lab, Princeton, NJ 08544 Princeton University
kevinpg@princeton.edu, mtwalsh@princeton.edu, RFeder@PPPL.gov, SCohen@PPPL.gov

A small, D-^{3}He-burning, field-reversed-configuration (FRC) fusion reactor has been proposed for direct-drive spacecraft propulsion.[1] Though the D-^{3}He reaction is *aneutronic,* D-D reactions will create 2.45 MeV neutrons; 14.1 MeV neutrons may be generated by D-T reactions of the T ash with the D fuel. The aim of this study is to ascertain how much shielding is needed to protect the reactor's superconducting magnetic coils from neutron damage and heat load. Because FRCs have high β and linear geometry, they require relatively low magnetic field strengths, <10 T, and, thus, may be able to use high temperature superconductors, reducing the conductor cooling-system mass, improving the rocket engines' specific power. It is critical to know the atomic species, mass, and volume of the shielding materials needed for the reactor to operate without extensive maintenance during extended, 1-100 year, missions.

We first describe the expected neutron generation rate, explaining how the neutron power can be reduced to ~1% or less of the fusion power. Then, by means of neutron transport analysis with the Attila code,[2] we show that, based on displacements-per-atom (DPA), as little as 16 cm of $^{10}B_4C$ shielding would be required to protect a 1 MW/m rocket engine's coils on a 310-day mission to and from Mars. (This relative thin shielding still represents *ca.* 40% of the rocket system's mass.) Other parameters, *e.g.,* He^4-build-up and heat load, were also quantified and found to be less important than DPA. We computed the neutron fluences and effects for a variety of shielding materials, *e.g.,* W inserts and isotopically enriched B_4C, and shielding configurations.

In addition to determining how these design changes affect the neutron fluence to the superconducting coils, we investigated the effects of these changes on the helium production, nuclear heating, and DPA in the inner vacuum vessel wall, the B_4C shielding, and the RF antenna used for plasma heating and current drive. In all cases, DPAs in the materials was the most significant factor. Heating due to the neutron radiation was a minor factor. Bremsstrahlung and synchrotron radiation from the plasma provides a much more significant heat load and thus would dominate design choices for cooling. Importantly, the OSHA-specified human dose necessitates 5-times more shielding that the coil DPA requirement, if humans were expected to perform operations within 1 m of the reactor for periods greater than 1 month/year.

[1] M.A. Paluszek, G. Pajer, Y. Razin, J. Slonaker, S.A. Cohen, R. Feder , K. Griffin, and M. Walsh, "Direct Fusion Drive for a Human Mars-Orbital Mission," Proceedings 65th International Astronautical Congress, Toronto (2014).

[2] Attila (Integrated Radiation Transport Simulation Environment), *Transpire*, Inc., a member of *Varian Medical Systems*.